Accuracy Analysis of GPS Positioning Near the Forest Environment

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Abstract – Nacrtak

GPS has become an essential tool for georeferencing. In some cases, GPS is used for unfavorable conditions although it was developed for open field studies. This paper analyzes the achievable accuracy and performance of GPS near the forest. Three surveying marks have been established with the distance seperation five meter in length. Two GPS campaigns were conducted for the selected marks in the forest. The same campaign was repeated once again after the forest was cut off. The experiments demonstrate the degradation of the GPS accuracy due to the forest. As a result, the largest horizontal accuracy errors were found to be in the forest. Horizontal accuracy errors were the smallest in the area without obstacles. Large vertical accuracy errors were produced in the forest; however vertical accuracy errors were also relatively small after the forest was cut off. The standard deviations improved by about 50–70% for both baselines and height differences when the forest was cut off. In conclusion, tree canopies greatly affected both horizontal and vertical accuracy.

Keywords: GPS, forest, accuracy, terrestrial measurements

1. Introduction – *Uvod*

Global Positioning System (GPS) has been applied successfully in many areas of forest industry. Typical applications include fire prevention and control, harvesting operations, insect infestation, boundary determination, and aerial spraying. The past scientific literature found that the equivalent accuracies could be obtained under a canopy compared with the open field. These results are not supported by recent studies. While the topic seems to be somewhat avoided in the relevant scientific literature (GPS not being for use in the non-open environment in the first place), it is still recurrent in many discussion lists on the web. Deckert and Bolstadt (1996) studied the effects of terrain, forest canopy, number of consecutive position fixes and Position Dilution of Precision (PDOP) on GPS accuracy. They found that the positional accuracy was higher for open sites compared to sub-canopy and higher for deciduous sites versus coniferous. Sigrist et al. (1999) discussed the impact of the forest canopy on quality and accuracy assessment of GPS measurements. Hasegawa and Yoshimura (2003) studied the performance of dual-frequency GPS receivers for static surveying under tree canopies.

Forest and natural resource applications can be achieved efficiently employing GPS data collection technologies. However, there are limiting factors in environments, such as forest canopy, that cause adverse effects on the reception of GPS signals. Steep terrain and heavy forest cover make GPS data capture slow due to reception of acceptable satellite coverage. So, position accuracy is often degraded in difficult terrain conditions, and in some cases it may not meet accuracy standards and requires resurveying. In the forests, canopy cover may interfere with satellite signal reception and make it difficult to make reliable measurements. The combined effects of forest cover and terrain will degrade the performance of all GPS receivers. The GPS signals are affected by the surrounding trees and earth and that affects adversely both accuracy (how close the lines and points are to their true location) and productivity (how much of the time the receiver is tracking enough satellites). The users are limited by the view of the sky in a tree canopy environment resulting in the GPS receiver to be locked to only high elevation satellites. Satellite constellation has a large effect on the quality of the data collected in forested environments such as data bias. Constantly changing constellations result in inconsistent and poor relative data accuracy. Forest canopy affects the GPS signals because of obstruction, attenuation, and reflection. So, line-of-sight GPS signals are obstructed by solid objects. The signal is blocked by tree trunks, larger branches, and terrain features such as mountains. The signals are weakened and attenuated by leaves and small branches. This attenuation can make it very difficult for a GPS receiver to track the signals. At some point, the receiver will not be able to track the signal at all and the effect will be the same as if the signal was obstructed. Even if the signal can be tracked, some receivers will have difficulty in measuring the pseudoranges accurately. The phenomenon of a satellite signal reaching an antenna by more than one path (direct and some reflected paths) is called multipath. This multipath can cause large variations in position estimates in a variety of environment, e.g., under forest canopy. The main effect of signal obstruction is to convey an increase in PDOP. As PDOP is related to the satellite geometry and number of satellites logged, a lower PDOP is expected when more satellites are observed. PDOP is a unitless measure indicating the quality of satellite geometry. When the satellites are spread around the sky, the PDOP value is low and the computed position is more accurate. In the case when satellites are grouped closely, the PDOP is high and positions are less accurate. As the PDOP is directly related to the position accuracy, more satellites and a lower PDOP will usually mean better accuracy under forest canopy. Modern GPS systems have been improved for the satellite tracking technology so that weaker signals can be observed under trees with foliage (Note that dense foliage will still cause cycle slips). In spite of this advanced tracking capability, the signals are noisier, weaker and more likely to be subject to multipath and diffraction. The surveyor should be aware that positions may not be accurate despite the quality indicators showing good solutions. To overcome this situation, the surveyors are required to check out the GPS results using a total station. In such cases, terrestrial survey can help productivity in difficult terrain conditions and be carried out to obtain an independent result of the position for assessing the accuracy of the GPS results in the forest environment (Parkinson and Spilker 1996, Hoffmann et al. 2000, Pirti 2005, Rabbany 2006). The aim of this study is to assess the achievable accuracy of GPS surveys under forest environment.

2. Material and Methods – *Materijal i metode*

In this paper two experiments are designed to show the effect of increasing relative distance to a tree canopy as well as quantifying the magnitude of multipath effect. The two experiments were performed in the Samandýra area of Istanbul, Turkey (Fig. 1). The GPS (static) measurements were taken both in the presence of a forest (July 30, 2003 – Day of year – DOY 211) and after the forest was cut off (September 16, 2003 – DOY 259), Fig. 2. To study signal multipath and diffraction effects on static GPS baselines due to forest, three stations (P1, P2 and P3) were located at a distance of about 0 m, 5 m and 10 m from the forest environment consisting of around 8–10 m tall pine trees (Fig. 2a). Starting with point P1 (the border of the forest), two other points with distances of about 5 m (P2) and 10 m (P3) from P1 were marked. Three stations were observed both using GPS and terrestrial measurement methods. In the first step of this study, GPS measurements were carried out for both situations either when the forest exists (Fig. 1a) or is cut off in the project area (Fig. 1b).

The data were recorded at three stations by static GPS measurements at time intervals of 6 hours.

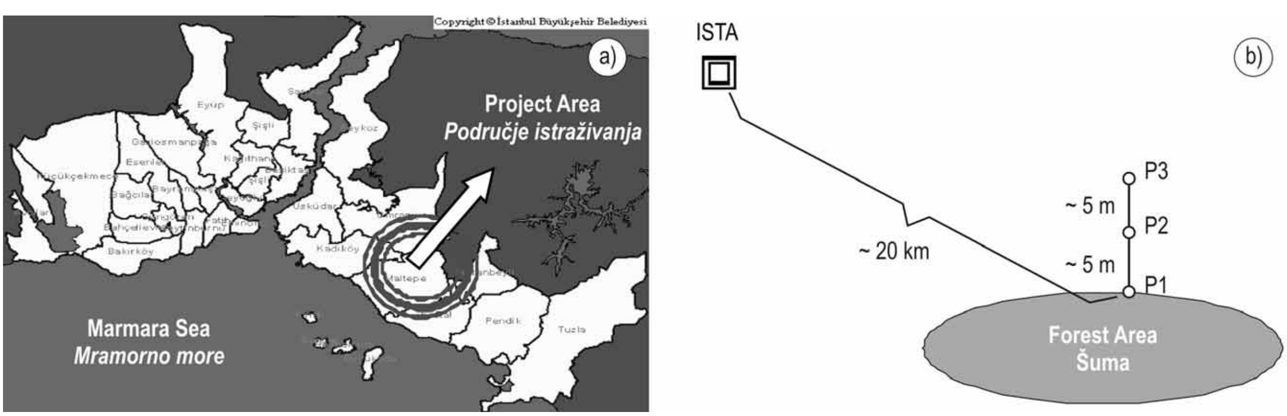
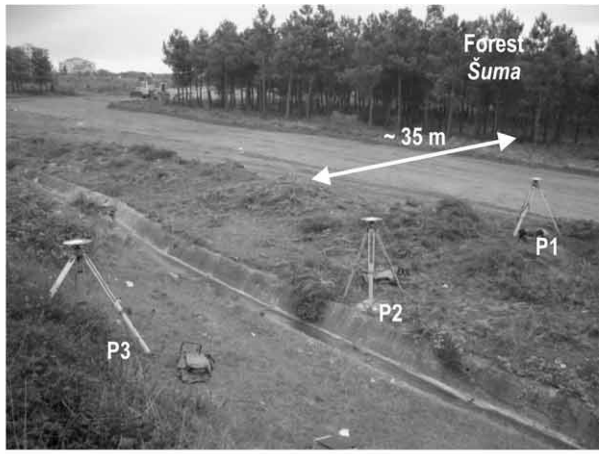


Fig. 1 Project area and GPS network
Slika 1. *Područje istraživanja i položaj GPS prijamnika*

a) on DOY 211 (with forest) – *u blizini šume*



b) on DOY 259 (without forest) – *nakon sječe šume*

Fig. 2 Stations in the project area
Slika 2. *Stajališta istraživanoga područja*

Three Ashtech Z Surveyor receivers and Ashtech geodetic antennas were used for the static GPS measurements. The coordinates of the three points were determined in two GPS sessions (with and without forest) with 5 seconds sampling interval, 10 degrees elevation cut-off for two days. The RINEX data obtained were processed with Bernese 5.0 GPS software in order to compute the coordinates of P3 for both sessions in ITRF 2000 on both days (see Tables 1 and 2). IGS reference station ISTA – (Fig. 1b) was fixed in the processing.

The forest cause severe obstruction of almost 50% of the sky for P1 on DOY 211 (Fig. 1b and Fig. 2a). The coordinates of P1 were much affected by the forest environment on DOY 211, and however, the coordinates of P3 were less affected on both days by forest environment than the other points. Therefore, the coordinates of P3 were fixed in the static and kinematic (epoch-by-epoch) processing by using Ashtech Solution 2.60 GPS Software to compute the coordinates of the other two points (P1 and P2) because of its far distance from the forest environment (Tables 1 and 2).

Table 1 Coordinates and standard deviations of three points in the project area on DOY 211
Tablica 1. *Koordinate i standardne devijacije za tri stajališta na istraživanom području prvoga dana mjerenja*

Point *Stajalište*	Coordinate *Koordinata*	Standard deviation *Standardna devijacija*	Coordinate *Koordinata*	Standard deviation *Standardna devijacija*	Coordinate *Koordinata*	Standard deviation *Standardna devijacija*
	φ_{ITRF}	σ_{φ}, mm	λ_{ITRF}	σ_{λ}, mm	H_{ITRF}, m	σ_H, mm
ISTA	41° 06' 16''.01024	0	29° 01' 09''.62368	0	147.246	0
P1	40° 58' 17''.48034	27	29° 12' 55''.88682	27	180.450	36
P2	40° 58' 17''.54318	27	29° 12' 56''.08298	27	179.738	36
P3	40° 58' 17''.59966	27	29° 12' 56''.28366	27	180.218	36

Table 2 Coordinates and standard deviations of three points in the project area on DOY 259
Tablica 2. *Koordinate i standardne devijacije za tri stajališta na istraživanom području drugoga dana mjerenja*

Point *Stajalište*	Coordinate *Koordinata*	Standard deviation *Standardna devijacija*	Coordinate *Koordinata*	Standard deviation *Standardna devijacija*	Coordinate *Koordinata*	Standard deviation *Standardna devijacija*
	φ_{ITRF}	σ_{φ}, mm	λ_{ITRF}	σ_{λ},, mm	H_{ITRF}, m	σ_H, mm
ISTA	41° 06' 16''.01024	0	29° 01' 09''.62368	0	147.246	0
P1	40° 58' 17''.48028	10	29° 12' 55''.88546	13	180.416	13
P2	40° 58' 17''.54320	10	29° 12' 56''.08319	13	179.731	13
P3	40° 58' 17''.59962	10	29° 12' 56''.28360	13	180.218	13

3. Results and discussion – *Rezultati s diskusijom*

P1–P3 and P2–P3 baselines were processed by Ashtech Solution 2.60 GPS Software in kinematic mode to investigate epoch-by-epoch variations of the coordinates (P3 fixed). The aim is to examine multipath and diffraction effects on the coordinate results. In data processing, x, y and h coordinate component residuals (Δx, Δy, Δh) of the two stations were obtained for every epoch. The residuals were referred to as the difference between the estimated coordinates and the reference ones for each epoch. Fig. 3a and Fig. 3b show epoch-by-epoch coordinate residuals of P1 on DOY 211 and 259, respectively. It was shown in Fig. 3a and 3b that the standard devia-

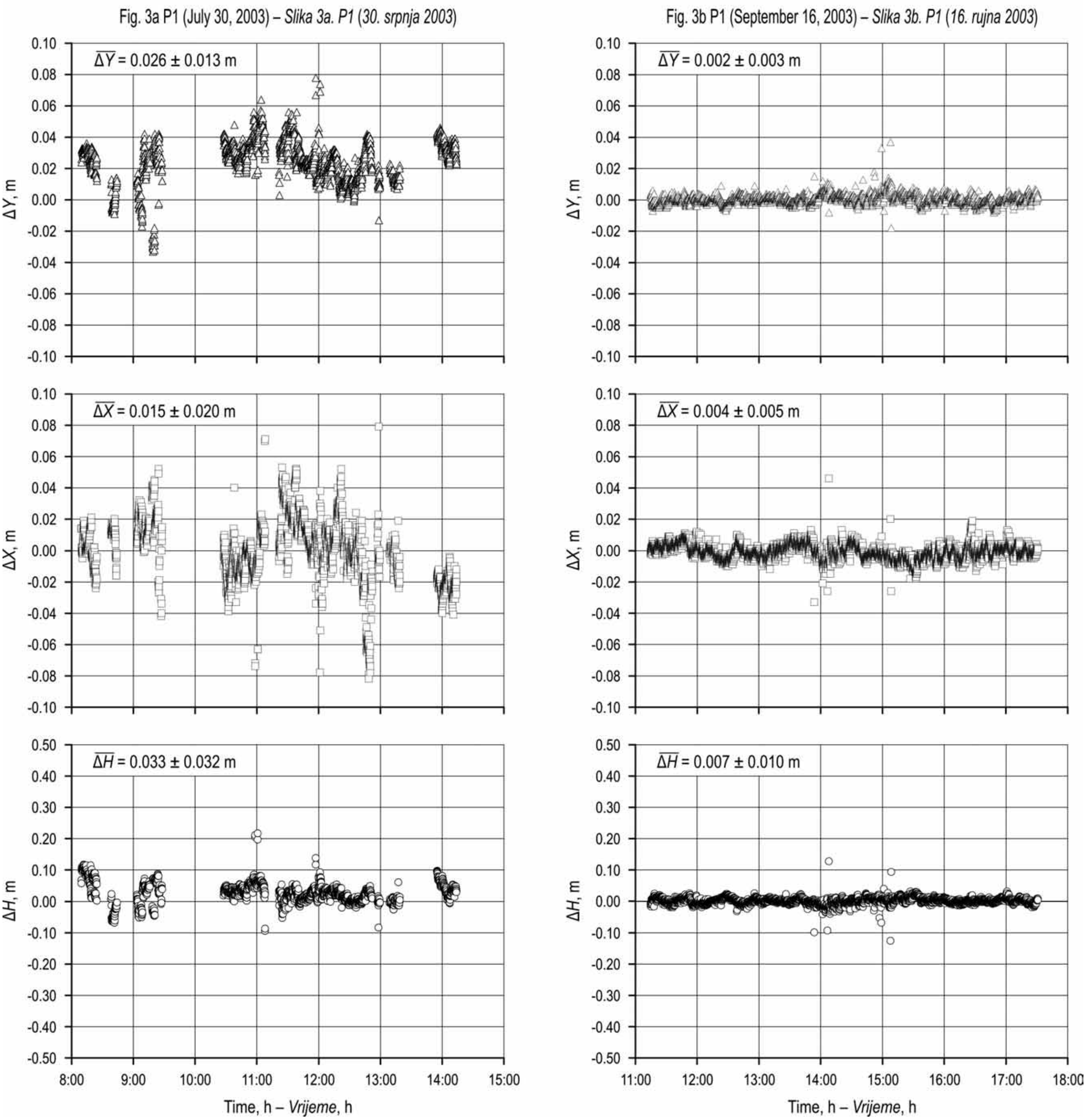


Fig. 3 Epoch-by-epoch processing results for P1
Slika 3. *Rezulati izmjere po epohama za stajalište P1*

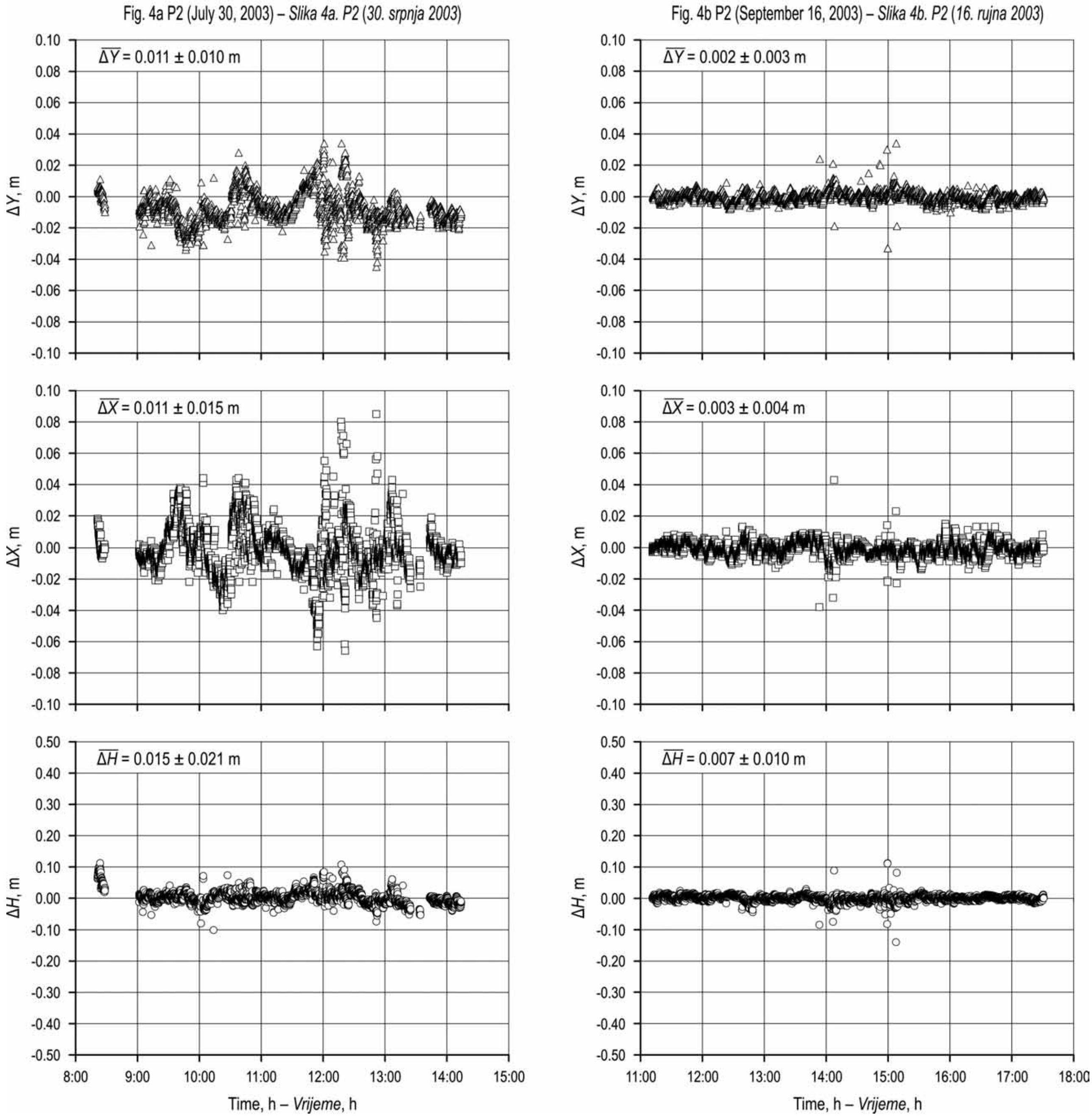


Fig. 4 Epoch-by-epoch processing results for P2
Slika 4. *Rezultati izmjere po epohama za stajalište P2*

tions and mean values of P1 on DOY 211 are considered to be a factor approximately three or four times larger than that of P1 on DOY 259. The standard deviations improved by about 70 to 80 percent for P1 when the forest was cut off. It is clear that the forest caused a significant bias in the coordinate residuals on DOY 211 (Fig. 3a). The time series of coordinate residuals of the GPS session confirm that there is a strong bias of about 10 cm in horizontal components and about 25 cm in height components on DOY 211 indicating that the forest causes significant multipath effect. At certain times, enough satellites were not tracked to fix the ambiguity value for P1, e.g., 9:30–10:30 UT (Fig. 3a).

The three components are presented for P2 on both days in Fig. 4. Fig. 4a shows epoch-by-epoch co-

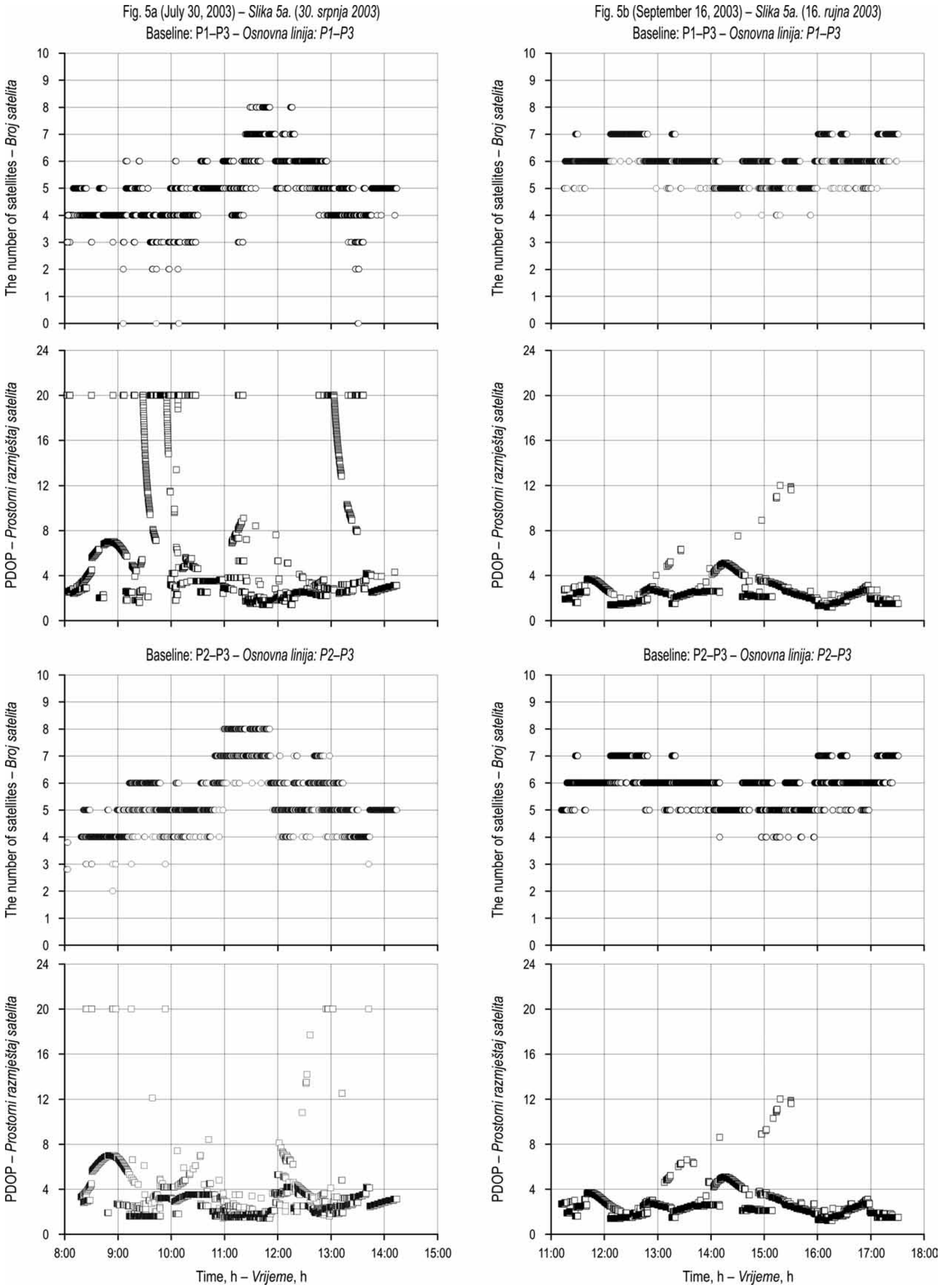


Fig. 5 PDOP and number of satellites for P1-P3 and P2-P3 baselines
Slika 5. *PDOP i broj satelita za osnovne linije P1-P3 i P2-P3*

Table 3 Mean values of the distances and height differences between two points by using the terrestrial and static GPS measurements
Tablica 3. *Srednje vrijednosti udaljenosti i visinske razlike između stajališta klasičnom metodom izmjere totalnom stanicom i izmjera statičnim GPS prijamnikom*

Baseline *Osnovna linija*	Distance – *Udaljenost*			Height difference – *Visinska razlika*		
	Terrestrial *Terenska*	GPS DOY 211 *Dan 1.*	GPS DOY 259 *Dan 2.*	Geo. levelling *Nivelacija*	GPS DOY 211 *Dan 1.*	GPS DOY 259 *Dan 2.*
	s, m			Δh, m		
P1–P3	10.020	9.985	10.013	±0.192	±0.232	±0.198
P2–P3	5.026	5.028	5.022	±0.491	±0.480	±0.487

ordinate results of P2 on DOY 211. P2 was mounted at a distance of about 5 m from the forest environment. These Δx and Δy components change between a few millimetres up to 10 cm on that day. The height component is, however, less consistent and sometimes shows differences up to 15 cm. Figure 4b shows coordinate residuals for P2 on DOY 259. It is also shown in Figures 4a and 4b that standard deviations and mean values of P2 on DOY 211 are considered to be a factor approximately two or four times larger than the following day. Again, the standard deviations improved by about 50 to 70 percent for P2 when the forest was cut off. It is clear that forest caused a significant bias in the coordinate results on

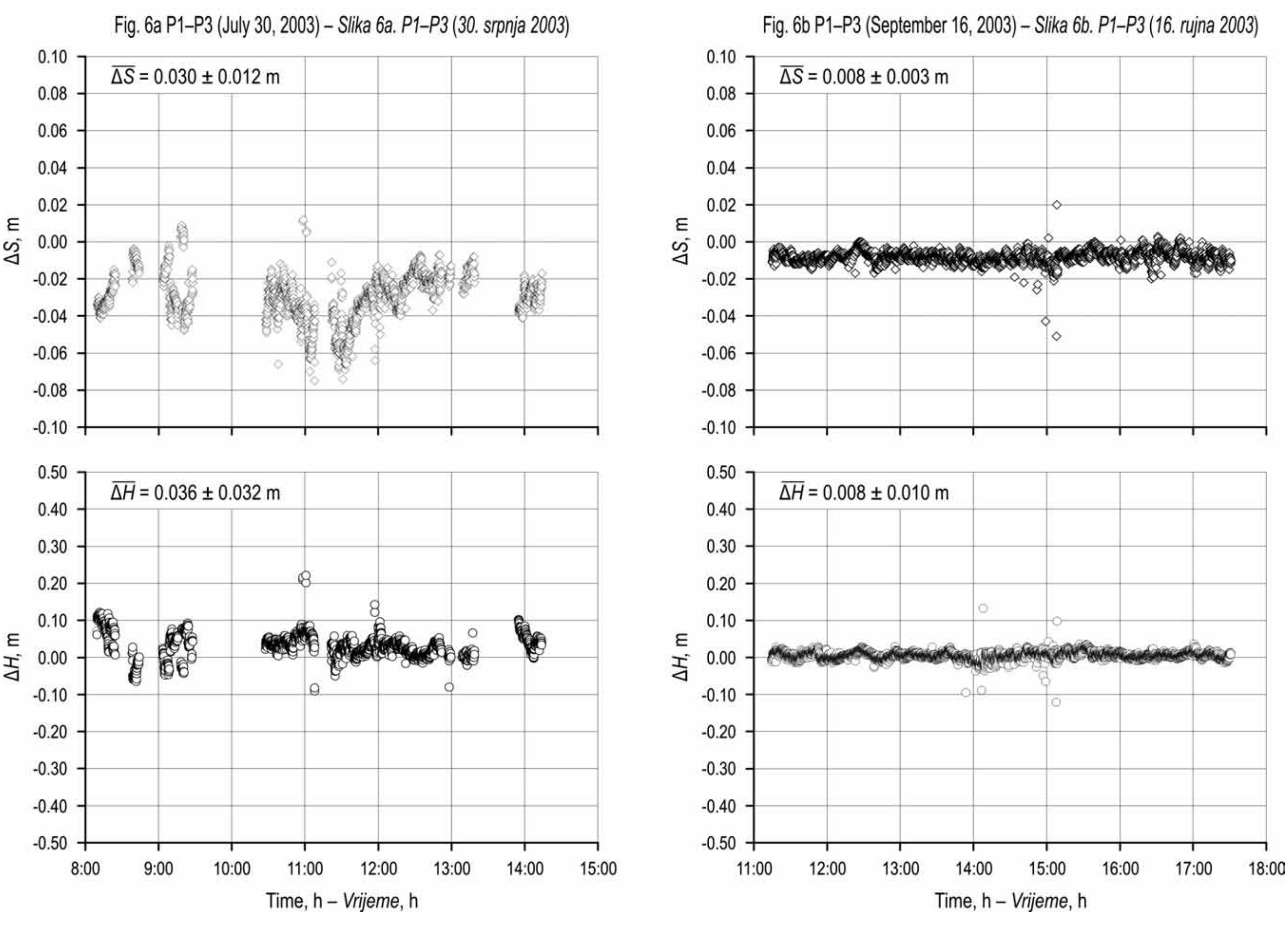


Fig. 6 The epoch by epoch changes of P1–P3 baseline (comparison of GPS and terrestrial survey)
Slika 6. *Promjene po epohama za osnovnu liniju P1–P3 (usporedba izmjere GPS-om i totalnom stanicom)*

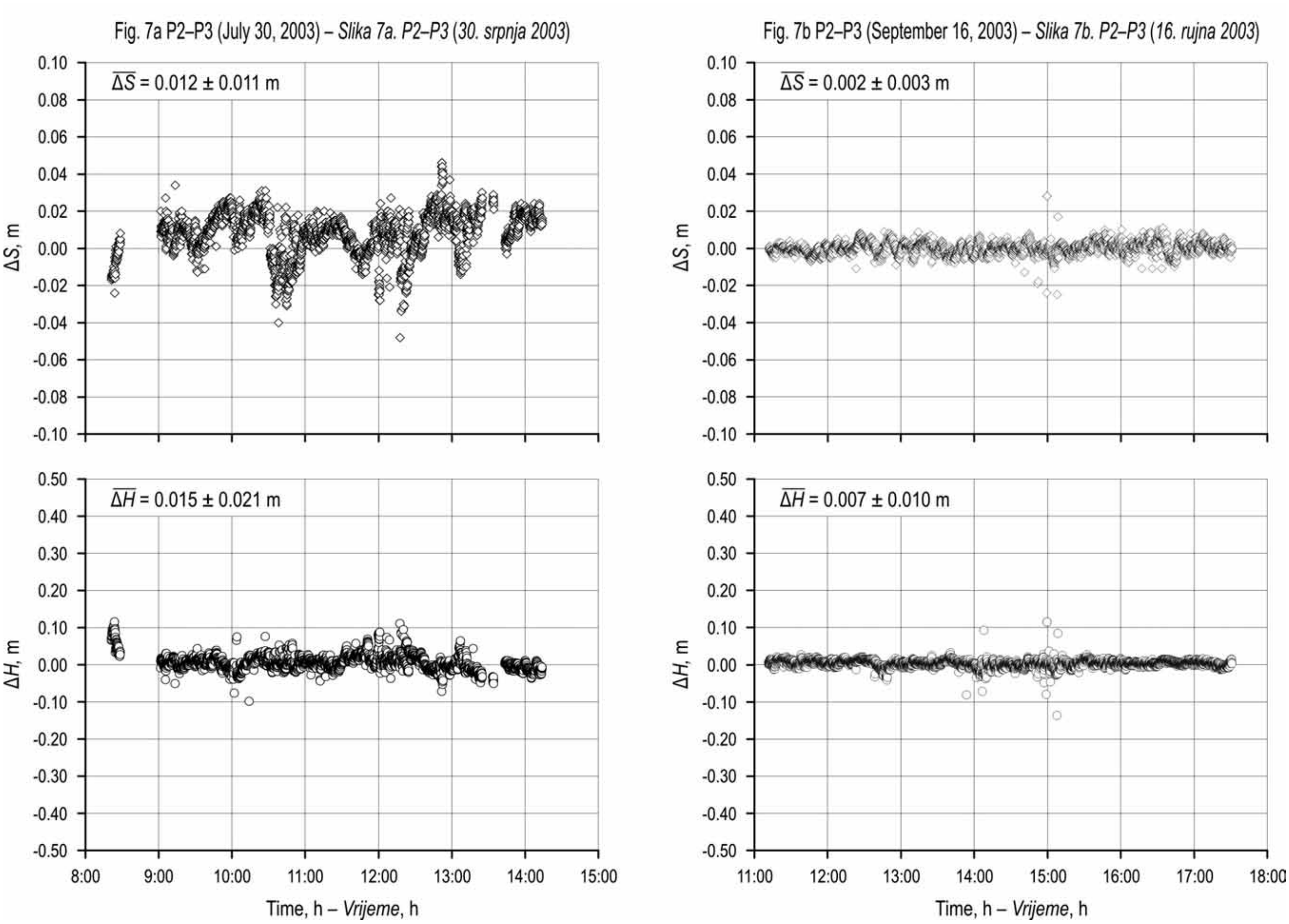


Fig. 7 The epoch by epoch changes of P2-P3 baseline (comparison of GPS and terrestrial survey)
Slika 7. *Promjene po epohama za osnovnu liniju P2-P3 (usporedba izmjere GPS-om i totalnom stanicom)*

DOY 211 (Fig. 4a). The epoch-by-epoch coordinates of the GPS session confirm that there is a strong bias of about 10 cm in horizontal components and 15 cm in height components indicating that the forest causes significant multipath.

The difference in precision between good and poor satellite configurations P1–P3 and P2–P3 baselines on both days can be seen in Fig. 5a and 5b. The PDOP changes according to the number and distribution of the satellites tracked. The good satellite configuration on DOY 259 results in small coordinate variations compared to the coordinate variations on DOY 211 for P1 and P2 (Fig. 3, 4 and 5). It is obvious that the epoch-by-epoch horizontal components are not affected by high multipath effects on DOY 259.

In order to compare the GPS results with those obtained by using an independent measurement method, distances between points were measured with a total station. Terrestrial surveys were used to check the static and kinematic (epoch by epoch) GPS results, especially for the spatial distances and height differences. Topcon DL-102 digital level surveying instrument (with a measurement accuracy of 1.5 mm/km) and a barcode rod were used to determine the height differences and Nikon DTM 330 Total Station (measurement accuracy for angles and distances ±1.5 mgon and distances 3 mm + 2 ppm, respectively) was used to measure spatial distances between all points. Distance and height measurements were made (10 series) and then the mean value of all measurements computed as shown in Table 3. In this test, the variation of the geoid was neglected since the distances are very close. The quality of the static GPS results was checked out against spatial distances and height differences determined by the terrestrial measurements. GPS and terrestrial methods show differences up to 4 cm for horizontal and vertical coordinates in the presence of multipath due to the forest environment, whereas about 1 cm for horizontal and vertical coordinates without forest environment (Table 3). As expected, P1 was mostly affected by multipath due to forest. This effect can be seen in the solutions of P1–P3. P2–P3 is less affected by the multipath since P2 and P3 points are installed further from the forest.

Fig. 6 shows epoch by epoch changes of the distance differences (Δ*S*) of P1–P3 differencing distances from total station and GPS. It is found that the variations were greater in height differences and smaller in distances at the project area. Figures 6a and 6b show the standard deviation of ΔS for P1–P3 as ±1.2 cm on DOY 211 and ±0.3 cm with and without forest, respectively. The mean value of distance difference for P1–P3 was 3.0 cm and 0.8 cm for the days with and without forest, respectively. The standard deviation of height difference (Δ*H*) variations for P1–P3 was ±3.2 cm on DOY 211 and ±1.0 cm on DOY 259 (Figures 6a and 6b). The mean value of the height difference for P1–P3 was 3.6 cm on DOY 211 and 0.8 cm on DOY 259. So, signal multipath due to forest environment affected the horizontal and vertical components. Positioning accuracy under forest canopy was considerably lower than the other case for horizontal and vertical components.

As for P2–P3, the standard deviation of ΔS for P2–P3 is ±1.1 cm on DOY 211 and ±0.3 cm on DOY 259 (Fig. 7a and 7b). The mean value of ΔS for P2–P3 is 1.2 cm in multipath environment, whereas 0.2 cm for the other case. The standard deviation of Δ*H* variations for P2–P3 is ±2.1 and ±1.0 cm; the mean values are 1.5 and 0.7 cm with and without forest, respectively. As a result, the signal blockage due to tree canopies could be considered as the main problem affecting the use of GPS near the forest environment despite the presence of good satellite windows. It is clear that the multipath effect disappears from the solutions as the forest is cut off. Improvements can be observed of up to 4 cm in both distance and height solutions. Naesset et. al (2000) demonstrate that accuracy can be achieved for static measurement under the forest canopy only within 1–9 cm. The obtained results in this paper are consistent with this study.

4. Conclusions – *Zaključci*

This study indicates that the extent of forest obstruction has a significant effect on the accuracy, precision and performance of GPS positions. The observation points should be carefully installed, i.e. distances to the forest border should be incremented so that the point is less affected by the multipath. Comparison of individual session solutions shows that the accuracy of GPS results was degraded for both horizontal and vertical components. As expected, the accuracy of the height component is about 2 or 4 times lower. The standard deviation of coordinate solutions gradually improves as the surveying station is moved away from the border of the forest. High multipath environment (forest) causes the standard deviations and the mean values of coordinate estimates to become lower by about 50–70%. Comparisons of GPS results with terrestrial surveys also reveal that the effect of tree canopy resulting in multipath effect is obvious. Spatial distances and height differences were degraded by about 4 centimeters.

5. References – *Literatura*

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Sažetak

Analiza točnosti pozicioniranja GPS-a uz šumski okoliš

U današnjem je svijetu GPS postao prijeko potreban alat za određivanje pozicije, tzv. georeferenciranje. GPS je također našao primjenu u različitim područjima šumarstva, kao što su uređivanje šuma, pridobivanje drva, zaštita šuma od požara i bioloških štetnika.

Korištenje GPS-a za prikupljanje podataka na šumskim područjima pokazalo se zahtjevnim, ali i učinkovitim. Međutim, postoje ograničavajući čimbenici, kao što su sastojinski sklop i konfiguracija terena, koji uzrokuju smetnje u prijmu GPS signala. Strmi tereni i gust sklop krošanja smanjuju kakvoću signala, zbog čega je preciznost određivanja pozicije nepouzdana i često ne zadovoljava propisane norme. Stalna promjena položaja satelita značajno utječe na kakvoću prikupljenih podataka u šumskim predjelima, što se očituje kao odstupanje u točnosti podataka. Debla i krošnje stabala slabe i ometaju signal, a to rezultira slabijom kakvoćom prikupljenih podataka, jer signal ne uspijeva stići do GPS prijamnika. Pojava pri kojoj satelitski signal dolazi do antene prijamnika različitim putovima naziva se višepuće. Upravo se zbog te pojave u području obraslom šumom događaju velika odstupanja u određivanju pozicije.

Kakvoća je signala također povezana s PDOP veličinom koja je u svezi s položajem satelita i brojem satelita čiji signal GPS prijamnici primaju. Kada su sateliti ravnomjerno raspoređeni, PDOP vrijednost je mala i izračun pozicije je točniji. U slučaju kada su sateliti grupirani, PDOP vrijednost raste, a točnost se određivanja pozicije smanjuje.

Cilj je ovoga istraživanja procijeniti moguću točnost u šumskom okolišu.

U ovom su radu oblikovana dva pokusa koji prikazuju utjecaj povećanja relativne udaljenosti u odnosu na krošnju stabla te kvantificiranje veličine višeputnoga efekta. Pokusi su obavljeni u okolici Istanbula, u području Samandira (slika 1).

Zbog potreba istraživanja višeputnoga signala i efekta distrakcije na statični GPS uređaj, tri su stajališta postavljena (P1, P2 i P3) na udaljenosti 0, 5 i 10 metara od sastojine (slika 2).

Na stajalištima je primijenjena klasična metoda izmjere totalnom stanicom i izmjere GPS prijamnicima. Podaci su prikupljeni pomoću prijamnika Ashtech Z Surveyor i pripadajućim geodetskim antenama Ashtech na svakom stajalištu.

GPS uređajem mjereno je na istom šumskom području u dva navrata: u neposrednoj blizini šume i na šumskoj površini nakon sječe.

Dobiveni su podaci (format RINEX) obrađeni pomoću aplikacije Bernese 5.0 GPS kako bi koordinate bile izračunate prema referentnomu koordinatnomu sustavu ITRF 2000 (tablice 1 i 2).

Sklop je sastojine prouzročio značajne smetnje pri prvom snimanju na stajalištu P1 jer je 50 % vidljivoga horizonta bilo zaklonjeno šumom. Za određivanje točnih koordinata kao referentno je uzeto stajalište P3 prema kojem su izračunate točne koordinate za preostala stajališta iz razloga što je to stajalište najmanje bilo pod utjecajem blizine šume.

Osnovne su linije P1–P3 i P2–P3 obrađene pomoću Ashtech Solution 2.60 GPS aplikacije kinematičkom metodom radi ispitivanja tzv. epoch-by-epoch oscilacije koordinata. Prilikom obrade podataka razlike su x, y i h varijabli dvaju GPS prijamnika dobivene za svaku epohu (za svaki podatak snimljen u pojedinom intervalu), a odnose se na razliku između referentnih i izmjerenih koordinata.

Slike 3a i 3 prikazuju razlike koordinatnih varijabli po epohama na stajalištu P1. Standardna je devijacija smanjena 70 – 80 % na stajalištu P1 nakon što je šuma posječena. Očito je kako šuma uzrokuje značajnu sustavsku pogrešku u razlici koordinatnih varijabli (slika 3a). Vremenski niz koordinatnih razlika pokazuje veliku sustavsku pogrešku od približno 10 cm za horizontalnu sastavnicu i 25 cm za visinsku sastavnicu zbog utjecaja blizine šume na pojavu višepuća.

Slike 4a i 4b prikazuju koordinatne varijable po epohama na stajalištu P2 za prvi i drugi dan mjerenja. Vodoravna se i okomita sastavnica mijenjaju u opsegu od nekoliko milimetara do 10 cm tijekom prvoga dana mjerenja. Standardna se devijacija smanjila za 50 % do 70 % drugoga dana mjerenja na šumskoj površini nakon sječe.

Razlika u preciznosti između povoljnoga i nepovoljnoga razmještaja satelita vidljiva je na slikama 5a i 5b. Vrijednosti PDOP-a mijenjaju se s obzirom na broj i vidljivost satelita.

Radi usporedbe rezultata GPS izmjere obavljena je također klasična izmjera totalnom stanicom Nikkon DTM 330. Razlike u izmjerenim rezultatima prikazane su u tablici 3. Vidljivo je značajnije odstupanje izmjerenih vrijednosti na pravcu P1–P3. Uzrok tomu je položaj stajališta P1 uz rub šume pri čemu sklop sastojine utječe na veće rasipanje podataka.

Srednje vrijednosti razlike udaljenosti između stajališta P1 i P3 iznose 3 cm tijekom prvoga dana mjerenja u blizini šume, odnosno 0,8 cm nakon sječe šume (slika 6a i 6b). Srednje vrijednosti visinske razlike između stajališta P1 i P3 iznose 3,6 cm tijekom prvoga dana mjerenja u blizini šume, odnosno 0,8 cm nakon sječe šume. Zaključuje se da je točnost izmjere značajno manja zbog utjecaja sklopa sastojine.

Na slikama 7a i 7b prikazane su srednje vrijednosti razlike udaljenosti i visinske razlike između stajališta P2 i P3.

Istraživanje je pokazalo da opseg smetnji prouzročen šumom ima značajan utjecaj na točnost, preciznost i rezultat određivanja GPS pozicije. Mjesta opažanja trebaju biti pažljivo postavljena, odnosno udaljenost od granice šume trebala bi biti povećana kako bi mjesta opažanja bila manje izložena pojavi višepuća. Usporedba rješenja pojedinih mjerenja pokazuje da je točnost smanjena i za horizontalnu i za vertikalnu sastavnicu. Preciznost visinske sastavnice je 2 – 4 puta manja od očekivane.

Standardna devijacija stupnjevito se poboljšava što je veća udaljenost snimanja od granice šume. Utjecaj okoliša, odnosno visok stupanj višepuća uzrokuje veću standardnu devijaciju i rasipanje srednjih vrijednosti rezultata za 50 – 70 %. Usporedba podataka dobivenih pomoću GPS prijamnika i klasična izmjera totalnom stanicom pokazuju kako je očit utjecaj sklopa sastojine na točnost izmjerenih podataka.

Ključne riječi: GPS, šuma, točnost, izmjera terena

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Received (*Primljeno*): March 17, 2008
Accepted (*Prihvaćeno*): September 11, 2008